The Ocean Algorithm Suite for the Conical-Scanning Microwave Imaging/Sounder (CMIS)

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Abstract- **The CMIS Ocean Algorithm Suite retrieves sea surface temperature (SST) as well as sea surface wind speed and direction. We Monte-Carlo simulate ocean brightness temperatures, which are received by the CMIS sensor using a physical radiative transfer model (RTM), geophysical parameters from a numerical weather prediction (NWP) model and add sensor errors. The SST and wind speed algorithms are statistical regressions. The algorithm for retrieving wind direction is a combination of statistical regressions, maximum likelihood estimate and median filtering. One part of the simulated data is used for tuning the algorithm and one part is retained for evaluating the algorithm performance.**

I. ORBIT AND SENSOR CHARACTERISTICS

The CMIS ocean suite uses 18 polarimetric CMIS channels operating at 5 different frequencies: 6.93 GHz VH, 10.65 GHz VHLR, 18.70 GHz VHLRPM, 23.80 GHz VH and 36.50 GHz VHPM. The CMIS orbits are near polar and the instrument is forward looking. The full orbit (ascending + descending) has 3200 scans and 300 cells per scan. The swath width is approximately 1700 km. The orbit geolocation is given as a set of geographical space (LAT, LON) and time coordinates as well as the looking azimuth and earth incidence angle for each observation (cell).

The radiometer noise is given as the product between NEDT and noise reduction factor (NRF) for the corresponding footprint size.

For the SST retrieval we utilize all channels between 6 and 37 GHz with a NRF for a 86 by 52 km footprint. For the high-resolution wind speed we utilize the 18–37 GHz channels with a NRF for a 20 by 20 km footprint. The algorithm for retrieving wind direction uses the 10–37 GHz channels and a NRF for a 56 by 35 km footprint.

We assume point like observations, no footprint averaging is performed.

II. SIMULATION OF BRIGHTNESS TEMPERATURES

The calculation of the true brightness temperatures is using a Radiative Transfer forward model, which is based on the physical theory of transfer of microwave radiation through the Earth's atmosphere and a semi empirical model describing the emission of microwaves from the ocean surface. Details can be found in [1]. The geophysical and orbital parameters, which determine the received brightness temperatures in the RTM are:

1. Earth Incidence Angle (EIA).
2. Surface Parameters: SST T_S, surface wind speed W and surface wind direction φ_r relative to the looking direction.
3. Atmospheric Parameters: Atmospheric transmission τ, and the up and downwelling atmospheric temperatures, T_{BU} and T_{BD}, respectively. The atmospheric parameters are determined by the atmospheric profiles for temperature, air pressure, water vapor and liquid cloud water. We consider only rain free atmospheres.

The geophysical parameters (2 and 3) beside clouds are provided by the NCEP FNL (GDAS real time final analysis), which is run 4 times daily (00Z, 06Z, 12Z, 18Z) and available on a 1deg LAT-LON grid. We interpolate the coordinates (LAT, LON, TIME) tri-linearly to the swath geolocations. The liquid cloud water is taken from SSM/I retrievals, which were done for all the days for which the simulations were run.

The Monte Carlo simulated brightness temperatures are obtained from the brightness temperatures of the RTM by adding Gaussian radiometer noise.

We have processed 5 orbits. One orbit is only used for tuning the coefficients in the regression algorithms (c.f. section III). The other 4 orbits are used for testing the retrieval quality. Each orbit contains approximately 400,000 – 500,000 valid observations.

III. REGRESSION ALGORITHMS FOR SST AND 20 KM -WIND SPEED

To retrieve SST and high-resolution (20 km footprint) wind speed we use statistical regressions. The EDR is expressed as sums $\sum_i c_i t_i$, with regression coefficients c_i and

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the t_i are functions of the measured brightness temperatures. The sums run over all channels for the SST retrievals, whereas for the high-resolution wind speed we only include frequencies between 18 and 37 GHz.

The RMS of the retrieved SST is 0.5 Kelvin or less. The RMS of the retrieved high-resolution wind speed is 1.0 m/s or less over the speed range between 0 and 25 m/s.

IV. WIND DIRECTION RETRIEVAL

A. Wind Direction Signal

The size of the wind speed signal is essential for the performance of the wind direction algorithm. Our simulations and retrievals are based on the most up to date analyses, which are [2] for the v and h-pol signal and [3] for the 3rd and 4th Stokes parameters. Inclusion of the polarimetric channels is indispensable for retrieving wind directions. Neither [2] nor [3] show a significant signal for wind speeds below 5 m/s. We therefore cannot expect good performance of the wind vector retrieval algorithm for low wind speeds.

B. Maximum Likelihood Estimate

The basis of the wind direction algorithm is a maximum likelihood estimate (MLE) that minimizes the sum of squares (SOS): $\chi^2 = \sum_i \left[T_{Bi} - F_i\left(W, \varphi_r, T_S, \tau, T_{BU}, T_{BD}\right)\right]^2$ between the measured brightness temperature for channel i and the RTM model function F_i. The sum runs over all channels between 10 and 37 GHz. The atmospheric parameters are found from linear regression similar as in section III and for the SST we used the retrieved value. We perform a 2-dimensional minimization for the SOS with respect to W and φ_r. This results in a set of solutions for the wind vector (ambiguities). The ambiguities are ranked in ascending order of their SOS value.

C. Ambiguity Selection by Median Filtering

In order to select the ambiguity closest to the true wind field we pass the ambiguities obtained from the SOS minimization through a circular vector median filter. The median filter cost function E has the form:

$$E_{ij}^k = \sum_{\substack{m=i-h \\ m \neq i}}^{m=i+h} \sum_{\substack{n=j-h \\ n \neq j}}^{n=j+h} \frac{1}{f(W_{mn})} \cdot \sqrt{\left(\vec{A}_{ij}^k - \vec{U}_{mn}\right)^2} . \qquad (1)$$

The window indices (m,n) do not include the window center (i,j). The index k runs over all ambiguities from 1 to the total number of ambiguities, which is between 2 and 4. $\vec{A}_{ij}^k$ is the field, which is currently passed through the filter. $\vec{U}_{mn}$ denotes the currently selected ambiguity, which serves as the filter. The filter is initialized with the first ranked ambiguity from the SOS minimization: $\vec{U}\left(start\right) = \vec{A}^1$. During each pass the ambiguity $\vec{A}^k$ that minimizes the cost function E^k is the newly selected one. The updating of the selected ambiguity is only done after all cells have been filtered.

For the median filter we have used only every 2nd scan and every 4th cell in each scan. This way our wind vector retrieval cells are approximately 20km in size, which is still smaller than the required size of 56 by 35 km. However, the NRF in the simulated brightness temperatures are the ones for the 56 by 35 km footprint. The number of valid wind vector retrievals is roughly 50,000 per orbit. We found better result for a window size of $h = 5$ than for $h = 3$, whereas increasing the window size beyond 5 did not improve the performance noticeably.

We have introduced a skill guidance weight function f(W), which has the form $f(W) = \left(1 - e^{-W^2/a^2}\right)^p$, where $a = 7.0\,{}^m\!/\!{}_s$ and $p = 1$. This skill weighting function attributes larger confidence and therefore a lower SOS value for areas where the wind speed is large and the skill is expected to be higher.

The median filter is terminated when the relative difference in the minimum cost function E, summed up over all cells, between pass N-1 and pass N reaches a threshold $\varepsilon = 10^{-3}$. It takes about 8-10 steps per orbit reach the termination condition. During the first pass about 3000 out of approximately 50,000 fields are changed per orbit, which is about 6%. The number of changed fields decreases in each step. During the last step before termination only about 50 fields are changed per orbit, which is about 0.1%.

D. Algorithm Performance

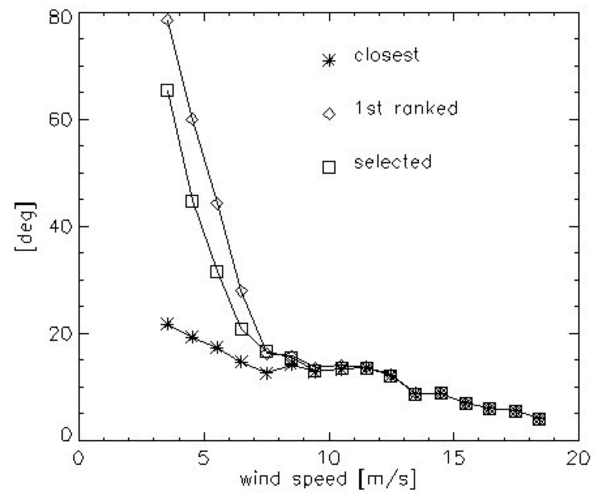

Figure 1: Standard deviation between true and retrieved wind speed. The figure shows the statistics for the ambiguity closest to the true wind vector (stars), the 1st ranked ambiguity from the MLE (diamonds) and the ambiguity selected by the median filter (squares).

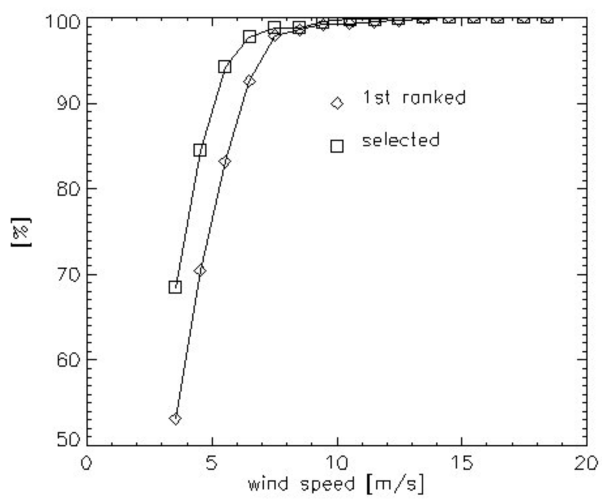

Figure 2: Skill rates for the 1st ranked ambiguity and the ambiguity that is selected by the median filter.

Figure 1 shows the standard deviation between the true and the retrieved wind direction as a function of wind speed. We show the results for the (1) ambiguity that is closest to the true wind speed, which is the best possible result, (2) the ambiguity that is 1st ranked by the MLE, i.e. the one with the lowest SOS and (3) the ambiguity that is selected by the median filter. Figure 2 shows the skill rate, which is defined as the rate how often the corresponding ambiguity matches the closest ambiguity.

REFERENCES

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